2004 Command and Control Research and Technology Symposium
The Power of Information Age Concepts and Technologies

The Multidimensional Measurements of Geographic Information Systems (GIS) Effectiveness in Crisis Management

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Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **JUN 2004**	2. REPORT TYPE	3. DATES COVERED **00-00-2004 to 00-00-2004**
4. TITLE AND SUBTITLE **The Multidimensional Measurements of Geographic Information Systems (GIS) Effectiveness in Crisis Management**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Ministry of Defense and Aviation,PO Box 102847,Riyadh 11685 Saudia Arabia, ,**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**25**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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Abstract

Geographic information systems (GIS) timely and precise spatial information for command and control systems. GIS support decision makers in formulating plans and making critical decisions in preparedness, response, recovery, and mitigation phase of crisis management. The study developed a validated and prioritized reference decision-making model by Panel of experts from Federal Emergency Management Agency (FEMA) that measures GIS effectiveness in crisis management. The model consists of seven factors and forty sub-factors.The seven GIS factors with respect to their importance in ascending order were system quality, information quality, user satisfaction, system use, decision performance, task complexity and feedback, and organizational impact.

The data on measuring GIS effectiveness were obtained from a survey. Analyzed results from GIS directors, project managers, technical staff and users indicated that user satisfaction was assessed the lowest factor in the model. Additionally, the lowest assessments of the model sub-factors were; error recovery, documentation of system and procedures, ease of learning, currency of output, top management involvement, training provided to user, and GIS organizational position. The highest assessments in the model sub-factor were given to presentation mapping, viewing the map, and productivity improved by GIS.

The major recommendations made include the following: (1) regularly measure the GIS effectiveness for each crisis events and establish a backlog; (2) consider some other measurements of technical, individual, and organizational factors based on GIS future capabilities, crisis context, and organization needs.

Keywords: Geographic information systems (GIS), crisis management, system quality, information quality, user satisfaction, system use, decision performance, task complexity and feedback, and organizational impact.

1. Introduction

We are able to witness an age of internationally and nationally growing crises. The increasing number of crises is happening because of the population increase, more people using urban high-risk areas, geological effects, meteorological changes, expanding infrastructure complexity, increasing threat of terrorism, and the complexity and value of advanced technology and its integration. Natural and man-made disasters can all be forms of crisis.

There are different forms of natural disasters such as tornadoes, earthquakes, floods, volcanoes and forest fires. Environmental problems and landslides could also be considered as natural disasters. Usually natural disasters cause great loss in terms of cost and people. Human-made disasters could be either accidental (technological) which may include construction failures, space, aviation and biological disasters, along with industrial chemical accidents, and information technology, or intentional incidents which may include terrorist actions or military conflict. A crisis may happen at any moment with or without any warning. A crisis may shake the political stability of a government or may destroy a private organization.

While disasters or crises may not be avoidable, they can be predicted, or their impact can be minimized. Timely and accurate spatial information produced by geographic information systems (GIS) are the keys to effective crisis management [1]. United States Geological Survey (USGS) [2] defined GIS as "system of computer hardware, software and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems."

Using GIS in command and control systems can enhance this information to reduce loss of lives, minimize the amount of crisis damage and save crisis recovery costs. GIS tools apply to the four phases of crisis management. These phases are preparedness, response, recovery and mitigation. Table 1 illustrates The GIS applications for each phase. Moreover, GIS can monitor and track the path of a disaster, and forecast potential problems with utilities or residential areas that could be threatened in upcoming days.

Table 1. GIS Applications & Time Requirements in Crisis Management Phases

Preparedness	Response	Recovery	Mitigation
T0		**T0 +72 hours**	
- Preposition resources	- Evacuation routs	- Damage assessment	- Integration with contingency plan
- Critical zones & estimates	- Emergency routs	- Alternative routs	- Restricted zones classification
- Demographic distribution	- Resources sites updates	- Projects monitoring	- Risk assessment
- Track & analyze incident	- Damage incidents areas	- Clean up and rebuild	

The critical problem in GIS practice is a failure to develop a valid model to measure GIS effectiveness for crisis applications. Therefore, based on a comprehensive relevant review of literature, the problem addressed in this study is:

There is a need to investigate multidimensional measurements of the geographic information systems (GIS) effectiveness in all phases of crisis management that incorporates technical, as well as individual and organizational factors. Moreover, there is a need to develop a more validated decision making model to prioritize the multidimensional GIS effectiveness factors, and to customize the model for measuring GIS effectiveness in crisis management.

In order to investigate the main research problem, the following research procedure are identified and shown in figure 1:

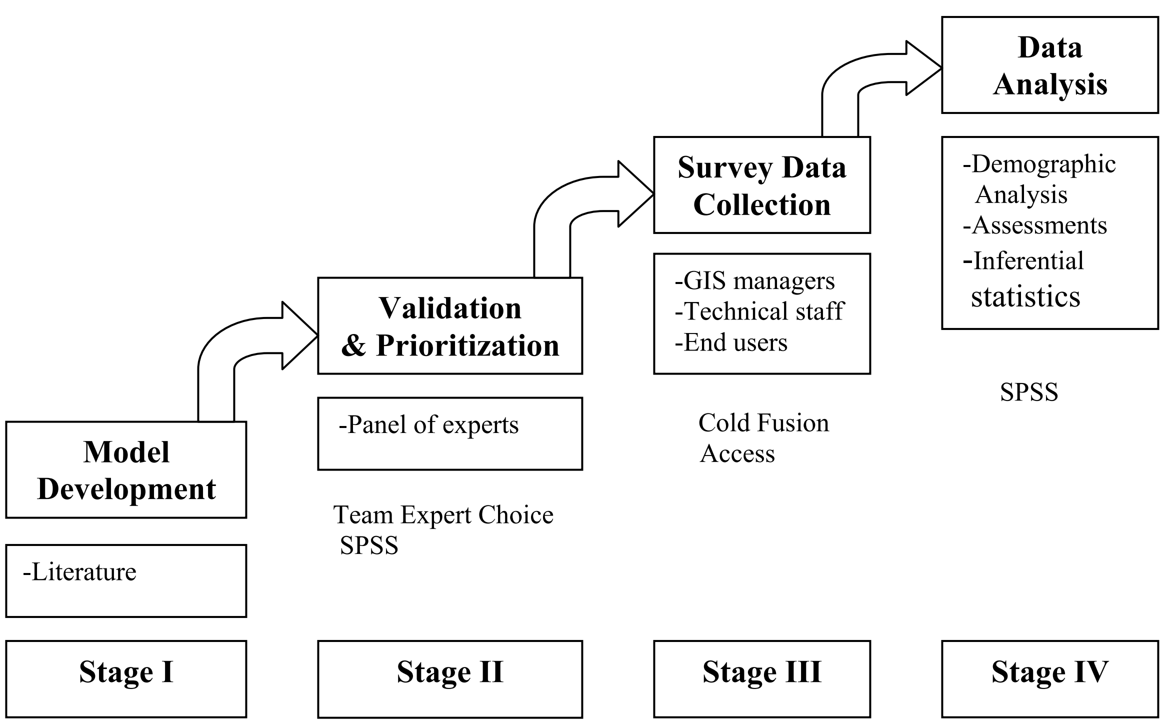
1. Develop a theoretical based model of GIS effectiveness in crisis management that combines technical, as well as individual and organizational factors.
2. Structure the developed model in a decision making model for validating and prioritizing the GIS effectiveness factors.
3. Measure and assess the GIS effectiveness factors in crisis management field using the model.
4. Investigate any significant differences in the GIS effectiveness in crisis management, using the model factors as dependant variables, through the following formulated research hypotheses.

   Research Hypothesis 1: There are significant differences in GIS effectiveness in crisis management among GIS directors and project managers, GIS technical staff, and GIS end users.

   Research Hypothesis 2: There are significant differences in GIS effectiveness in crisis management among GIS users based on their years of work experience.

   Research Hypothesis 3: There are significant differences in GIS effectiveness in crisis management among GIS users based on duration of training.

Figure 1. Research Procedure



2. GIS Effectiveness Model

There is a very limited research on the evaluation of geographic information systems effectiveness. Since GIS are spatial information systems, a comprehensive survey of literature on the evaluation of information systems effectiveness will add great value in developing a model for measuring GIS effectiveness.

The literature review is the primary source for identifying evaluation criteria associated with the effectiveness of GIS application in crisis management. Though the focus of this study is on GIS effectiveness in crisis management, the evaluation criteria for measuring the effectiveness of information systems will be used accompanied with specific criteria for GIS [3] [4]] [5]] [6]. Moreover, an adopted definition for measuring GIS effectiveness is necessary for this study. The USGS defined GIS effectiveness based on the definition of the General Accounting Office (GAO) [2] for information system effectiveness which is "system effectiveness is measured by determining whether the system performs the intended function and whether users get the information they need, in the right form, in a timely fashion."

In 1949, Shannon and Weaver defined communication theory levels, which demonstrate that information in communication systems can be measured at different levels. Those levels include the technical level, the semantic level and the effectiveness level. The technical level is the accuracy and efficiency of the system which produces the information, the semantic mode is conveying the information to meaning, and the effectiveness level is the effect of the information on the receiver [7].

Later in 1978, Mason had adopted the communication theory to the information system field. He defined effectiveness as influence that consists of three levels. Those three levels are the receipts of the information, the influence on recipient by evaluating the information and its application, and the influence on the system performance through a change in recipient behavior [6] [7].

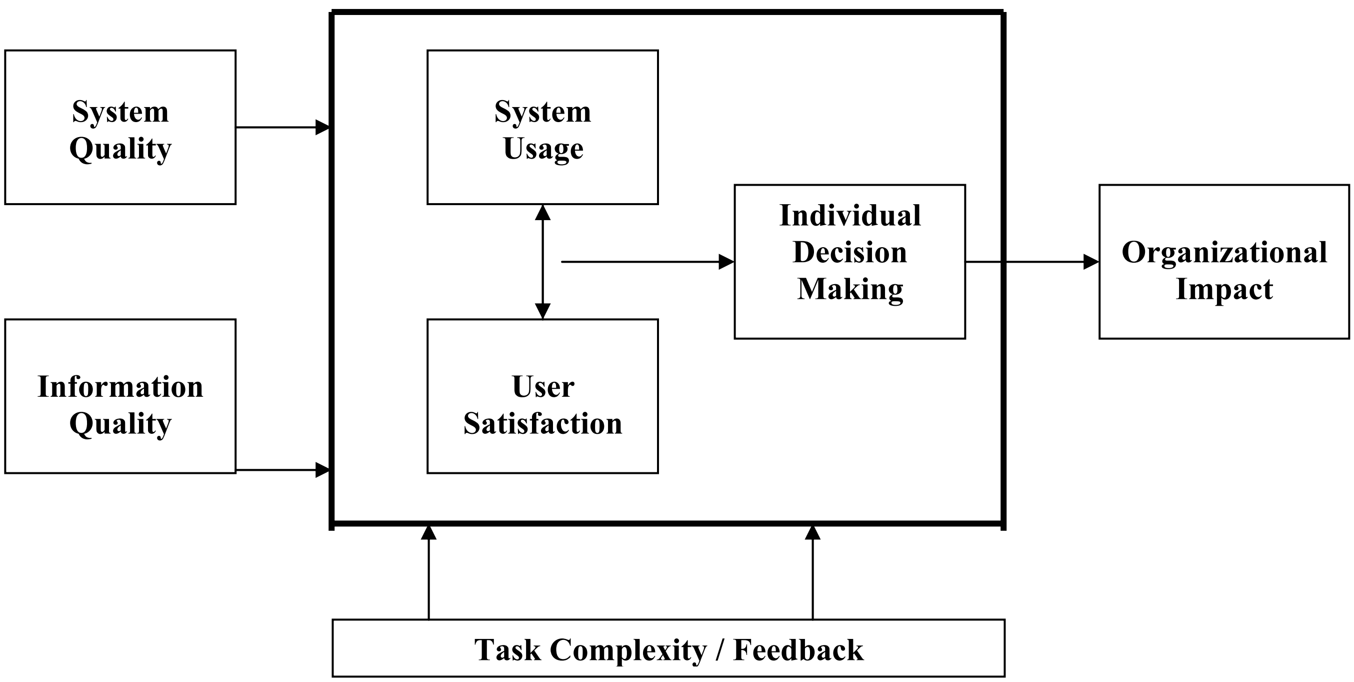
In 1992, Delone and McLean [7] reviewed a total of 180 research articles that proposed different aspects of information systems success or effectiveness with different measurements. Their contribution to the information systems field was the introduction of a taxonomy that presents researchers with an integrated view of the dependent variable for information systems success. They proposed a model of six major dimensions for measuring information systems success. The six measurements are system quality, information quality, use, user satisfaction, individual impact and organizational impact. The dimensions are interdependent on each other and researchers are advised to combine measures from each dimension to form comprehensive instruments for measuring information systems success. Moreover, they noted that "once this expanded view of information systems success is recognized, it is not surprising to find that there are so many different measures of this success in the literature, depending upon which aspect of information systems the researcher has focused his or her attention. Some of these measures have been merely identified, but never used empirically. Others have been used, but have employed different measurements, making comparisons among studies difficult" [7] .

There are many reasons to indicate that Delone and McLean's model is a strong and well-developed model for measuring information systems effectiveness. First, it is built based on a standard theoretical basis. It was based on Shannon and Weaver`s 1949 communication theory and the modification done by Mason, 1978, as discussed above. Second, it provides a multidimensional approach for independent variables of

Information Systems. This is based on their thorough research for 180 articles of information systems success. Third, some researchers have applied this model, or part of the model. They indicated some success and validity of their results [8] [9].

Though a number of effectiveness measures have been identified in the literature under various names, some studies do not fit exactly into any one dimension of the Delone and Mclean model. Arnold [10] has modified Delone and McLean's model. This modification was based on some criticism of some research studies that apply to Delone and McLean's model or part of that model. The modified model is shown on Figure 2.

Figure 2. Geographic Information Systems (GIS) Effectiveness Model
Source: Vicky Arnold, "Discussion of an Experimental Evaluation of Measurements of Information System Effectiveness," Journal of Information Systems, vol 9, no. 2 (fall 1995): 85-91.



Arnold added one factor which consists of task complexity and feedback. This is an important extension to Delone and McLean's model and adds significant contribution to information systems literature [10]. Moreover, Arnold's model shows that the individual impact factor is closely related to and is represented by decision performance which is the degree to which the system supports or improves decision making. In other words, it is the effect of the system on the performance outcome for an individual decision-maker, or its collective effects on the department or the organization.

The unique attempt of this research is to adopt Arnold's model to measure (GIS) effectiveness. The seven integrated factors of this model that will be used are:

- System Quality: is the measurement of the information processing system. It is used to assess the performance of the information systems.
- Information Quality: focuses on the quality of information systems produced output.
- System Usage: is the extent and nature of the use of the output of an information system.
- User Satisfaction: is the degree to which the system users are satisfied with information system.
- Individual Decision Making: is the effect of information on the behavior of the recipient.
- Task Complexity and Feedback: is the degree to which work to be performed is difficult to understand and uncertain [11]. Feedback is the loop process from past behavior to current attitudes and beliefs [12].
- Organizational Impact: represents the effect of information that is produced by an information system on organizational performance.

After identifying the seven factors that will measure GIS effectiveness, the next step is to identify the sub-factors or attributes for each factor. Those sub-factors are collected from the previous research studies for information systems evaluation and from GIS feature [3] [13] [14] [15] [16] [17]. The organizing of those sub-factors and their definitions are explained below.

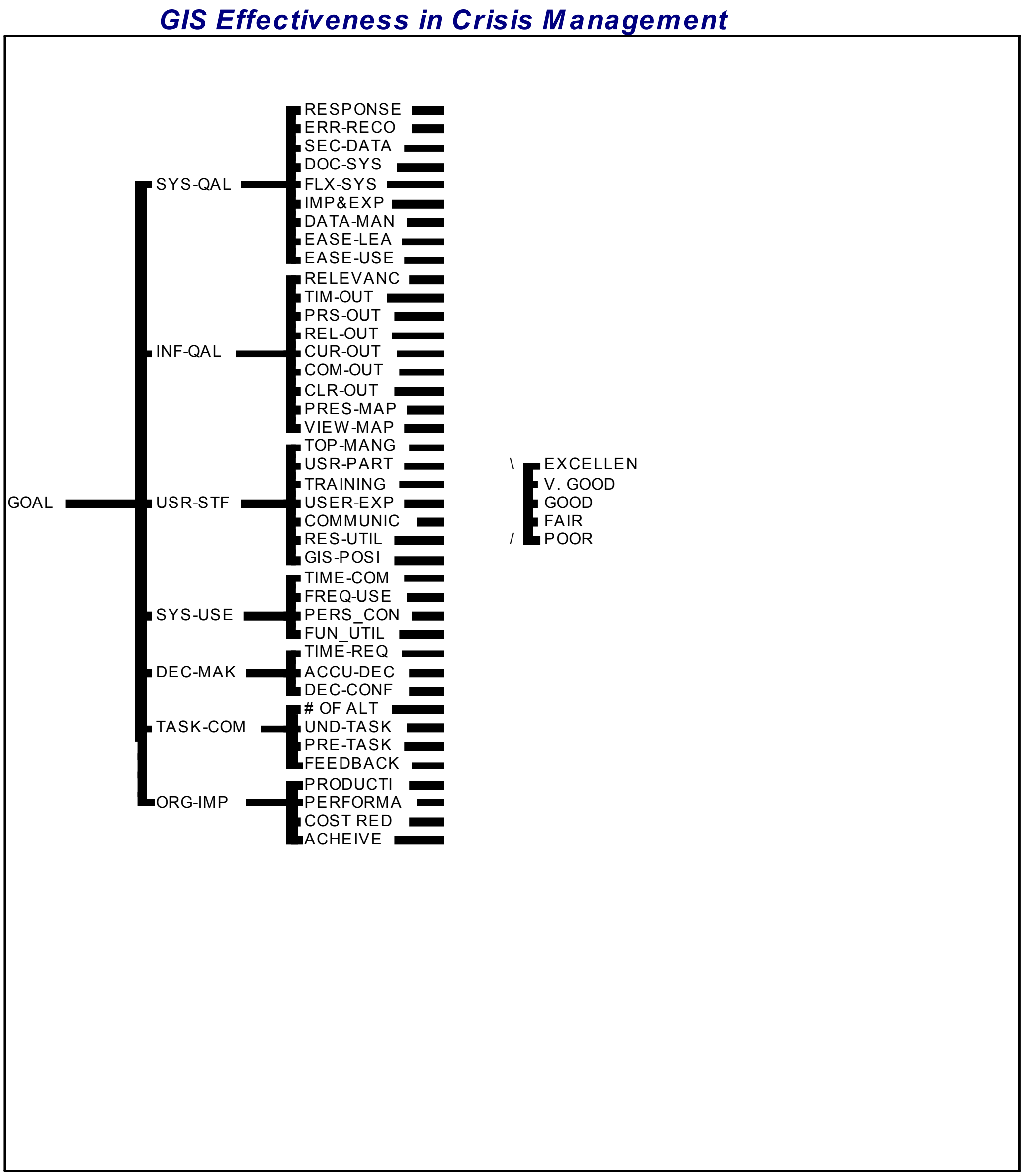
3. GIS Effectiveness Model Validation and Prioritization Exercise

In this second stage of research design, the theoretical model was structured in a decision making model for validation and prioritization exercise with Federal Emergency Management Agency (FEMA) panel of experts using group decision support software called Team Expert Choice. The researcher selected Team Expert Choice software to develop a multi-criteria decision-making model of GIS effectiveness in crisis management. Team Expert Choice model employs the Analytical Hierarchy Process (AHP) theory to generate GIS effectiveness priorities. Satty [11] introduced AHP and addressed how to determine the relative importance of a set of activities in a multi-criteria decision problem. AHP has been applied in a wide variety of practical settings to model complex decision problems. AHP makes it possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria. AHP has been used in ranking, selection, evaluation, optimization, and prediction decision problems. The process utilizes pairwise comparisons of the multiple criteria as well as pairwise comparisons of the multiple sub-criteria. The use of such comparisons to collect data from the decision-maker offers significant advantages. It allows the decision-maker to focus on the comparison of just two objects. Additionally, pairwise comparisons generate meaningful information about the decision problem, improve consistency in the decision making process [11].

The AHP structures the various factors or criteria of the decision problem into an upside-down tree structure. At the top of the model is the goal, which is GIS effectiveness in crisis management. The intermediate level in the tree represents the objectives or factors to take into consideration when making a specified decision. The GIS objectives or factors of this research model are system quality, information quality, user satisfaction, system use, decision performance, task complexity and feedback, and organizational impact. Another level of sub-objectives or sub-factors is located under the objectives. Figure 3 shows the built model by the Team Expert Choice, which also

shows the forty GIS sub-objectives. The definition of each sub-factor abbreviation is shown in Table 1.

Figure 3. The Team Expert Choice Model of GIS Effectiveness in Crisis Management



Once comparison matrices of the second and third level of the model are constructed, the final step is to determine the overall prioritization of the objective factors of GIS effectiveness in crisis management. Team Expert Choice provides a 9-prong scale as a basis for comparison between any two elements. They are as follows:

1 indicates equal importance of two elements;

3 indicates moderate importance of one over the other;

Table 1. Definitions of the Team Expert Choice Model Abbreviations

	Abbreviation	Definition
	SYS-QAL	**SYSTEM QUALITY**
1	RESPONSE	Response / turnaround time
2	ERR-RECO	Error recovery
3	SEC-DATA	Security of data and models
4	DOC-SYS	Documentation of system and procedures
5	FLX-SYS	Flexibility of the system
6	IMP&EXP	Import and export data
7	DATA-MAN	Data manipulation
8	EASE-LEA	Ease of learning
9	EASE-USE	Ease of use
	INF-QAL	**INFORMATION QUALITY**
10	RELEVANCE	Relevance
11	TIM-OUT	Timeliness of output
12	PRS-OUT	Precision of output
13	REL-OUT	Reliability of output
14	CUR-OUT	Currency of output
15	COM-OUT	Completeness of output
16	CLR-OUT	Clarity of output
17	PRES-MAP	Presentation mapping
18	VIEW-MAP	Viewing the map
	USR-STF	**USER SATISFACTION**
19	TOP- MAN	Top management involvement
20	USR-PART	User participation
21	TRAINING	Training provided to user
22	USER-EXP	User's expectation of GIS based support
23	COMMUNIC	Communication between users & technical staff
24	RES-UTIL	Resource utilization
25	GIS -POSI	GIS organizational position
	SYS-USE	**SYSTEM USAGE**
26	TIME-COM	Time to complete a task
27	FREQ-UAE	Frequency of use
28	PERS-CON	Personal control over GIS use
29	FUN-UTIL	Number of GIS functions utilized
	DEC-MAC	**INDIVIDUAL DECISION-MAKING**
30	TIME-REQ	Time required to make decisions
31	ACCU-DEC	Accuracy of the decision
32	DEC-CONF	Decision confidence
	TASK-COM	**TASK/FEEDBACK**
33	# OF ALT	Alternative output considered
34	UND-TASK	Understanding the task performed
35	PRE-TASK	Predictability of task results
36	FEEDBACK	Feedback from manager/staff/field
	ORG-IMP	**ORGANIZATIONAL IMPACT**
37	PRODUCTI	Productivity improved by GIS
38	PERFORMA	Performance improvement
39	COST-RED	Cost reduction
40	ACHEIVE	Achieve organization goals

5 indicates strong importance of one over the other;
7 indicates very strong importance of one over the other;
9 indicates extreme importance of one over the other;

and 2, 4, 6, and 8 indicate intermediate values between two adjacent judgments. Since there are no alternatives to be evaluated, an intensity rating scale is added. This level acts as an intensity scale for measuring each GIS model factor. The rating scale for this exercise is Excellent, Very Good, Good, Fair, and Poor.

3.1 *The Group Decision Making Participants*

Six experts from the Information Technology Services Directorate/Mapping and Analysis Center at the Federal Emergency Management Agency (FEMA) participated in the group decision-making exercise. This is because FEMA is the federal agency that bears primary responsibility for the nation's emergency management systems. Moreover, all participants that took part in the exercise of the Team Expert Choice model of GIS effectiveness in crisis management have used GIS for all types and phases of crisis management. The positions of the participants in the Team Expert Choice are:

1. Director of Mapping and Analysis Center.
2. Team leader of the GIS and software development team.
3. Two GIS analysts.
4. GIS technician.
5. Lead geographer.

The researcher acted as a facilitator when using Team Expert Choice for the group of the decision-making experts of FEMA. The researcher was responsible for operating the program, navigating with it, and directing the flow of discussion for the at FEMA during the exercise. Each expert at FEMA treated as decision-makers. They had a keypad that was used to enter their judgments in the system. After all experts have entered all judgments, the data for each criterion or objective is added together and averaged out. The average is then entered as a priority for that objective. After all of the weights have been recorded, Team Expert Choice generates the global weights of the nodes by combining the local priorities throughout the entire model.

3.2 *GIS Model Validation and Prioritization Exercise Results*

A pretest of the model survey was conducted with FEMA experts to make sure that those measures are appropriate in terms of both accuracy and feasibility. After that, some minor modifications were made to the sub-objectives and its measurements in the model. Based on that validation, GIS experts conducted 39 pairwise comparison assessments through the help of the facilitator (researcher). They entered their judgments for each comparison of GIS factors (first level) and sub-factors (second level). Team Expert Choice calculated the geometric mean for all of the comparison judgments by the panel of GIS experts for each objective or sub-objective. For each set of the pairwise comparison, mathematical calculations were performed that produce priorities (weights) and included a measure of judgmental consistency.

Table 2 represents the assigned local priority for the first level (seven objectives) and the second level (forty sub-objectives) of the model hierarchy. For the first hierarchy, factors within organizational impact were the most important. Organizational impact received a weight of (0.504) out of one. This means that organizational impact represents about 50% of the importance when it was compared with the other six factors of GIS

Table 2. Local Priorities of GIS Effectiveness Factors

NO	OBJECTIVE (FACTOR)	PRIORITY
	SYSTEM QUALITY	**0.025**
1	Response/turnaround time	0.048
2	Error recovery	0.026
3	Security of data and models	0.055
4	Documentation of system and procedures	0.105
5	Flexibility of the system	0.223
6	Import and export data	0.114
7	Data manipulation	0.107
8	Ease of learning	0.128
9	Ease of use	0.194
	INFORMATION QUALITY	**0.054**
10	Relevance	0.069
11	Timeliness of output	0.036
12	Precision of output	0.054
13	Reliability of output	0.159
14	Currency of output	0.089
15	Completeness of output	0.120
16	Clarity of output	0.275
17	Presentation mapping	0.120
18	Viewing the map	0.079
	USER SATISFACTION	**0.077**
19	Top management involvement	0.028
20	User participation	0.057
21	Training provided to user	0.090
22	User's expectation of GIS based support	0.106
23	Communication between users & technical staff	0.217
24	Resource utilization	0.307
25	GIS organizational position	0.193
	SYSTEM USAGE	**0.042**
26	Time to complete a task (Short=Excel, Long=Poor)	0.305
27	Frequency of use (Many=Excel, Few=Poor)	0.168
28	Personal control over GIS use	0.272
29	Number of GIS functions utilized	0.254
	INDIVIDUAL DECESION-MAKING	**0.127**
30	Time to make decisions (Short=Excel, Long=Poor)	0.189
31	Accuracy of the decision	0.490
32	Decision confidence	0.321
	TASK/FEEDBACK	**0.171**
33	Alternative output considered (Many=Excel, Few=Poor)	0.148
34	Understanding the task performed	0.324
35	Predictability of task results	0.240
36	Feedback from manager/staff/field	0.288
		0.504
37	Productivity improved by GIS	0.190
38	Performance improvement	0.239
39	Cost reduction	0.151
40	Achieve organization goals	0.420
	Total	**1.000**

effectiveness in crisis management. The second most important group of factors was the task complexity and feedback, which received (0.171) out of one. This indicates that task complexity and feedback represents about 17% of the importance when compared with the other factors of GIS effectiveness in crisis management. The third most important group of factors was individual decision making, which received a weight of (0.127) out of one. This means individual decision making represents about 13% of the importance when compared with the other factors of GIS effectiveness in crisis management. The fourth most important group of factors was user satisfaction, which received a weight of (0.077) out of one. This means that user satisfaction represents about 8% of the importance when it was compared with the other factors of GIS effectiveness in crisis management. The fifth most important group of factors was information quality, which received a weight of (0.054) out of one. This means information quality represents about 5% of the importance when compared with the other factors of GIS effectiveness in crisis management. The sixth most important group of factors was system use, which received a weight of (0.042) out of one. This indicates system use represents about 4% of the importance when compared with the other factors of GIS effectiveness in crisis management. The sixth most important group of factors was system use, which received a weight of (0.042) out of one. This indicates system use represents about 4% of the importance when compared with the other factors of GIS effectiveness in crisis management. And the last group of factors was the system quality, which received a weight of (0.025) out of one. System quality represents about 3% of the importance of the GIS effectiveness factors.

The global priority of the second level of the hierarchy was calculated and ranked by sorting from the lowest to the highest as shown in Table 3. The pairwise comparison judgments indicated that all participants agreed on the Response/turnaround time, error recovery, and security of data and models have the lowest priority in the model of 0.001. They ranked the least important when compared with the other thirty-seven GIS factors. However, the highest priorities of GIS factors in the model achieved were organization goals, performance improvement, and productivity improved by GIS and have weights of 0.211, 0.121, and 0.096 respectively and ranked the most important.

3.3 *Establishing Intensity Scale for Research Instrument*

Since there are no alternatives to be evaluated, an intensity scale was created to rate or assess the forty GIS effectiveness sub-objectives or sub-factors in the GIS instrument survey. The GIS instrument is based on the theoretical and validated GIS effectiveness model. In constructing intensity scales, the intention should be made to convey the information about the sub-objective being rated and to use ranges that are logical to the evaluator. The ratio ranges of the intensity scale do not have to be equal in span. The ratio scale values should represent the reality found in the work environment. The GIS panel of experts at FEMA participated to derive a new customized intensity ratio scale by prioritizing the intensity nodes through the usual pairwise comparison process in Team Expert Choice. After being prioritized, they may be thought of as a measurement scale for each GIS sub-objective.

Table 3. Global Priority of GIS Effectiveness Factors

NO	SUB-OBJECTIVE	PRIORITY
1	Response/turnaround time	0.001
2	Error Recovery	0.001
3	Security of data and models	0.001
4	Timeliness of output	0.002
5	Top management involvement	0.002
6	Documentation of system procedures	0.003
7	Import and export data	0.003
8	Data manipulation	0.003
9	Ease of learning	0.003
15	Currency of output	0.005
16	Flexibility of the system	0.006
17	Completeness of output	0.006
18	Presentation mapping	0.006
19	Training provided to user	0.007
20	Frequency of use	0.007
21	User's expectation of GIS based support	0.008
22	Reliability of output	0.009
23	Number of GIS functions utilized	0.011
24	Personal control over GIS use	0.012
25	Time to complete a task	0.013
26	Clarity of output	0.015
27	GIS organizational position	0.015
28	Communication between users & technical staff	0.017
29	Resource utilization	0.024
30	Time required to make decisions	0.024
31	Alternative output considered	0.025
32	Decision confidence	0.041
33	Predictability of task results	0.041
34	Feedback from manager/staff/field	0.049
35	Understanding the task performed	0.055
36	Accuracy of the decision	0.062
37	Cost reduction	0.076
38	Productivity improved by GIS	0.096
39	Performance improvement	0.121
40	Achieve organization goals	0.211

The FEMA experts identified and prioritized a scale with five distinct ratings. These ratings were Excellent (0.561), Very good (0.253), Good (0.118), Fair (0.045), and poor (0.023). Once the model is used for rating instead of alternatives, the global weights

of the intensity scale for rating the GIS factors were transferred to a normalized scale from one to zero. The new weights of the normalized intensity scale are listed in the Table 4.

Table 4. Intensity Scale Weights

Intensity Scale	Intensity Priority	Normalized Priority
Excellent	0.561	1.00
Very Good	0.253	0.45
Good	0.118	0.21
Fair	0.045	0.08
Poor	0.023	0.04

4. GIS Effectiveness Factors Assessments

4.1 *Survey Instrument*

Based on the theoretical and validated GIS model, the survey instrument was developed. The survey consists of two parts. The first part is to collect demographic data that includes organization type, organization size, GIS software, crisis phases, the respondent is position, GIS work experience, and GIS training duration. The second part of the survey is to assess the forty sub-factor of GIS effectiveness in crisis management. The assessments were based on the intensity scale identified by FEMA experts as explained above, and ranged from excellent being (1.0) to poor being (0.04). Moreover, the survey instrument was pre-tested by FEMA experts.

A cross sectional survey was used to collect data at one point in time from a sample selected to describe some larger population at that time. In order to choose a research sample that properly reflects the entire population under consideration, a random sampling procedure was utilized. Fifty-four government and private organizations participated in this research selected from FEMA and the United States Geological Survey (USGS) email list. The sample subjects consisted of GIS directors, GIS project managers, GIS technical staff, and GIS users. The technical staff includes system administrators, team leaders, programmers, and system analysts. The population sample needed to have hands-on experience with GIS applications, for small-scale emergencies such as fire or chemical incidents or large-scale disasters such as tornado, flood or hurricane events.

Three methodologies were used to distribute the survey. The first was through the distribution of the survey in GIS conferences and seminars. The second was through the mail. And the third was through a web page developed for the survey using the Cold Fusion Server software version 4.0. The data collected through the web was linked to ACCESS database, and the researcher was able to view the data. The URL address for the survey web page was sent to the subjects by email. The email addresses of the subjects were obtained from the United States Geological Survey (USGS) email list of GIS professionals in crisis and disaster application. Other email addresses were obtained from GIS conferences and seminars. One thousand one hundred and thirty four surveys were distributed by the means of the above three methods. One hundred eighteen

completed survey forms were collected. Eighty-seven survey forms were collected by the use of the web page and the thirty-one were collected by the other two methods. Ninety-eight answered survey data forms were used for the analysis and twenty collected survey forms were discarded due to missing data or being unusable. The data collected from the survey were analyzed to measure and assess the GIS factors effectiveness in crisis management (third stage), and to investigate any significant differences among survey respondents as independent variables in term of their position, level of experience, and training in the effective utilization of GIS factors as dependant variables, through the formulated research hypotheses (fourth stage).

4.2 *Reliability Analysis*

Reliability can be estimated from empirical data. The reliability of the instrument is concerned with its consistency. This research used the Cronbach's alpha value in order to assess the internal consistency of the results across items within a test. Alpha values above 70% are acceptable indicators of internal consistency [12]. Alpha values were calculated for each sub-scale. Table 5 shows the value of the reliability test for the main seven factors of the GIS effectiveness in crisis management.

From the table, one may see that the two lower reliability scores are system use and task complexity and feedback. The corresponding reliabilities were 74% and 79%. They are the weakest in the results nevertheless they pass the benchmark of 70% that is customarily used for internal consistency. Moreover, the questions that were designed under those two factors were developed by the researcher and have not been widely used to measure effectiveness of other types of information systems when compared with the other five factors. In addition, of the 98 respondents, only 84 of them had complete answers to the 40 items. There were 14 subjects chose not to answer some questions that explains the variability of the sample size within each sub-scale.

4.3 Demographic Variables Analysis

Table 6 shows the analysis of the demographic variables. These variables are: organization types (government or private), organization size (large to medium or small), GIS software (ArcInfo, ArcView, MGE, MapInfo, ERDAS, and others), crisis type (natural, technological, human made, and others), crisis phase (preparation, response, recovery, and mitigation), the respondent position (GIS directors or project manager, GIS technical staff, and GIS user), GIS work experience (Less than 2 years, between 2 to 6 years, and more than 6 years), and GIS training duration (Less than 6 months, between 6 to12 months, and more than a year).

4.4 Survey Data Analysis

Table 7 shows the results of the average assessments and the calculated standard deviation for GIS factors from the ninety-eight survey participants with their relative weights that were obtained from the GIS experts. The assessment of actual systems results for all of the survey participants indicates that low assessments (averages less than 0.30) were given to the following sub-factors; error recovery (0.29), documentation of system and procedures (0.26), ease of learning (0.27), currency of output (0.28), top management involvement (0.29), training provided to user (0.28), and GIS organizational position (0.25). Further investigation needs to be conducted in these areas for GIS applications in crisis management. Higher assessments (averages more than 0.45) were given to the sub-factors of presentation mapping (0.49), viewing the map (0.49), and

productivity improved by GIS (0.47). This indicates that all survey participants agreed that those areas were very well developed in GIS. Moreover, user satisfaction factor were assessed the lowest (0.30) and organizational impact were assessed the highest (0.44).

Table 5. Reliability Analysis of the GIS Effectiveness Factors

GIS Sub-Scale	Priority (%)	No. of Items	Sample Size	Reliability
System Quality	2.5	9	84	0.88
Information Quality	5.4	9	88	0.91
User Satisfaction	7.7	7	91	0.84
System Usage	4.2	4	94	0.74
Individual Decision Making	12.7	3	88	0.85
Task Complexity / Feedback	17.1	4	88	0.79
Organizational Impact	50.4	4	86	0.93
All Objectives	1.00	40	84	0.97

Table 6. Demographic Variables Analysis

NO.	ITEM	SAMPLE SIZE	Percentage
1. A	GOVERNMENT ORGNIZATIONS	72	73%
B	PRIVATE ORGANIZATIONS	26	27%
2. A	MEDUIM TO LARGE BUSINESS	76	78%
B	SMALL BUSINESS	22	22%
3. A	ARCINFO	53	54%
B	ARCVIEW	72	73%
C	MGE	15	15%
D	MAPINFO	33	34%
E	ERDAS	17	17%
F	OTHER GIS SOFTWARE	37	38%
4. A	NATURAL DISASTER	87	89%
B	TECHNOLOGICAL CRISIS	51	52%
C	HUMAN CRISIS	44	45%
D	OTHER TYPES OF CRISIS	23	23%
5. A	CRISIS PREPAREDNESS	73	74%
B	CRISIS RESPONSE	79	81%
C	CRISIS RECOVERY	60	61%
D	CRISIS MITIGATION	51	52%
6. A	DIRECTORS & PROJECT MANAGERS	41	42%
B	TECHNICAL PERSONAL	37	38%
C	USERS	20	20%
7. A	GIS WORK EXPERIENCE LESS THAN 2 YEARS	12	12%
B	GIS WORK EXPERIENCE BETWEEN 2 TO 6 YEARS	37	37%
C	GIS WORK EXPERIENCE MORE THAN 6 YEARS	49	50%
8. A	GIS TRAINING LESS THAN 6 MONTHS	30	31%
B	GIS TRAINING BETWEEN 6-12 MONTHS	17	17%
C	GIS TRAINING MORE THAN 1 YEAR	51	52%

Table 7. GIS Effectiveness Factors Assessments

NO.	OBJECTIVE (FACTOR)	PRIORITY	ASSESSMENT MEAN	SD
	SYSTEM QUALITY	**0.025**	**0.35**	
1	Response/turnaround time	0.001	0.42	0.21
2	Error recovery	0.001	0.29	0.19
3	Security of data and models	0.001	0.32	0.21
4	Documentation of system and procedures	0.003	0.26	0.17
5	Flexibility of the system	0.006	0.33	0.19
6	Import and export data	0.003	0.40	0.24
7	Data manipulation	0.003	0.42	0.23
8	Ease of learning	0.003	0.27	0.17
9	Ease of use	0.005	0.31	0.22
	INFORMATION QUALITY	**0.054**	**0.38**	
10	Relevance	0.004	0.40	0.20
11	Timeliness of output	0.002	0.37	0.17
12	Precision of output	0.003	0.32	0.19
13	Reliability of output	0.009	0.33	0.19
14	Currency of output	0.005	0.28	0.18
15	Completeness of output	0.006	0.30	0.20
16	Clarity of output	0.015	0.39	0.24
17	Presentation mapping	0.006	0.49	0.23
18	Viewing the map	0.004	0.49	0.24
	USER SATISFACTION	**0.077**	**0.30**	
19	Top management involvement	0.002	0.29	0.18
20	User participation	0.004	0.39	0.19
21	Training provided to user	0.007	0.28	0.19
22	User's expectation of GIS based support	0.008	0.34	0.21
23	Communication between users & technical staff	0.017	0.30	0.18
24	Resource utilization	0.024	0.30	0.19
25	GIS organizational position	0.015	0.25	0.17
	SYSTEM USAGE	**0.042**	**0.36**	
26	Time to complete a task (Short=Excel, Long=Poor)	0.013	0.31	0.18
27	Frequency of use (Many=Excel, Few=Poor)	0.007	0.39	0.21
28	Personal control over GIS use	0.012	0.39	0.23
29	Number of GIS functions utilized	0.011	0.38	0.21
	DECISION PERFORMANCE	**0.127**	**0.37**	
30	Time to make decisions (Short=Excel, Long=Poor)	0.024	0.33	0.22
31	Accuracy of the decision	0.062	0.38	0.21
32	Decision confidence	0.041	0.37	0.22
	TASK / FEEDBACK	**0.171**	**0.35**	
33	Alternative output considered (Many=Excel, Few=Poor)	0.025	0.33	0.21
34	Understanding the task performed	0.055	0.34	0.18
35	Predictability of task results	0.041	0.35	0.20
36	Feedback from manager/staff/field	0.049	0.37	0.18
	ORGANIZATIONAL IMPACT	**0.504**	**0.44**	
37	Productivity improved by GIS	0.096	0.47	0.26
38	Performance improvement	0.121	0.44	0.23
39	Cost reduction	0.076	0.38	0.21
40	Achieve organization goals	0.211	0.42	0.24
	Total	**1.000**		

5. Inferential Analysis of the Data

Inferential analysis was the fourth stage in this research. Inferential analysis of the data was conducted to examine the five null research hypotheses derived from the research hypotheses and was based on the parametric statistic one-way analysis of variance (ANOVA). Prior to applying (ANOVA) for each hypothesis, the validity of the assumptions associated with this statistic was examined and satisfied for the seven GIS effectiveness factors. These assumptions are normality of the distribution, independence of the observations, and Homogeneity of the variance. As far the homogeneity of the variance, the Levene test was utilized. Once ANOVA determines that the effect of some independent variable is significant which indicates that differences exist among the means, Tukey test of post hoc testing is used to make pairwise multiple comparisons that can determine which means differ. The null hypothesis is rejected when the likelihood of the observed difference in means occurring by chance (reported by the ρ-value) is less than 0.05, which is the level of significance. In those cases we assume there is a statistically significance difference between the two means.

Research Hypothesis 1: There are significant differences in GIS effectiveness in crisis management among GIS directors and project managers, GIS technical staff, and GIS users as perceived in system quality, information quality, user satisfaction, system use, individual decision making, task complexity and feedback, and organizational impact.

Test Findings: According to the test result presented, there is no significant difference among GIS position subgroups in the areas of system quality, information quality, user satisfaction, and individual decision making. The null hypothesis was retained; the analyzed data did not provide sufficient evidence to reject the null hypothesis for those specific four factors of GIS effectiveness in crisis management. However, the null hypotheses were rejected in the other three areas of GIS effectiveness in crisis management: system use, task complexity/feedback, and organizational impact. The analyzed data provides sufficient evidence for a significant difference between the GIS technical staff and GIS users. The technical staffs have significantly higher assessments than users as perceived in system use, task complexity/feedback, and organizational impact in GIS effectiveness in crisis management as explained below.

Test Analysis:

A) System use: Levene's test indicates that the homogeneity of the variance for all of the three tested GIS positions is met. Therefore, the ANOVA was utilized for the analysis. The ANOVA results are $F= 3.963$ and $\rho= 0.022<0.05$, which indicates that there is a statistical significant differences among the three subgroup of GIS positions in the effective utilization of GIS in crisis management. Further investigation was needed to find which subgroup is different. This was achieved by utilizing the post hoc Tukey test. The test reported a significant difference level of $0.020<0.05$ between GIS users with a reported mean 0.26 and GIS technical staff with a reported mean 0.41, but the GIS directors and project managers subgroup with a reported mean 0.38 does not differ from either with a significant level of $0.788>0.05$ with technical staff and $0.069>0.055$ with users. This could be interpreted as the technical personnel are more at ease and aware in utilizing the GIS capabilities for crisis applications than the end users.

B) Complexity/feedback: The homogeneity of the variance from Levene's test for all of the three tested GIS positions subgroups shows $\rho= 0.007<0.05$, which indicates a heterogeneity of the variance. Therefore, the analog non-parametric Kruskal-Wallis test was used instead of the parametric ANOVA test. The chi-square test results show significant differences among the three subgroups of GIS positions in the task complexity

and feedback since ρ= 0.021<0.05. Therefore, further investigation was needed to find which subgroup is different. This is achieved by utilizing the post hoc Tukey test. The test reported a significant difference in GIS task complexity/feedback with a level of 0.015 < 0.05 between GIS users with a reported mean 0.25 and GIS technical staff with a reported mean 0.43. However, the GIS directors and project managers subgroup with a reported mean 0.34 does not differ from technical staff and users with a significant level of 0.271>0.05 with technical staff and 0.278>0.055 with users. This might be attributed to the fact that users have less experience with GIS tasks in crisis applications and less understanding of the power of the system than the technical personnel.

C) <u>Organizational impact</u>: The homogeneity of the variance from Levene's test for all of the three tested GIS positions subgroups shows ρ=0.036<0.05, which indicates a heterogeneity of the variance. Therefore, the analog non-parametric Kruskal-Wallis test was used instead of the parametric ANOVA test. The chi-square test results show significant differences among the three subgroups of GIS positions in the organizational impact since ρ= 0.047<0.05. Therefore, further investigation was needed to find which subgroup is different. This was achieved by utilizing the post hoc Tukey test. The test reported a significant difference in GIS organizational impact with a level of 0.035<0.05 between GIS users with a reported mean 0.31 and GIS technical staff with a reported mean 0.51. However, GIS directors and project managers subgroup with a reported mean 0.45 does not differ from users or technical staff with a significant level of 0.694>0.05 with technical staff and 0.141>0.05 with users. This could be argued that users represent the lower managerial level in their organizations, which makes them unaware of the indirect positive impact of GIS on the organizations when compared with the technical personnel.

<u>Research Hypothesis 2:</u> There are significant differences in GIS effectiveness in crisis management among GIS users based on their years of work experience as perceived in system quality, information quality, user satisfaction, system use, individual decision making, task complexity and feedback, and organizational impact.

Test Findings: According to the test result presented, there is only significant difference among GIS experience subgroups: beginners (less than 2 years), professionals (between 2-6 years), and experts (more than six years) in the effectiveness of GIS system quality in crisis management and the null hypothesis was rejected. The analyzed data provides sufficient evidence for a significant difference between the GIS experts and GIS professionals. The experts are significantly higher assessed the GIS than professionals in their perception of the system quality effectiveness in crisis management. However, the null hypothesis was retained; the analyzed data did not provide sufficient evidence to reject the null hypothesis for the other six factors of GIS as explained below.

Test Analysis:

A) <u>System quality</u>: The homogeneity of the variance from Levene's test for all of the three tested GIS users experience subgroups shows ρ=0.001<0.05, which indicates a heterogeneity of the variance. Therefore, the analog non-parametric Kruskal-Wallis test was used instead of the parametric ANOVA test. The chi-square test results show significant differences among the three subgroups of GIS positions in the system quality since ρ= 0.038<0.05. Therefore, further investigation was needed to find which subgroup is different. This is achieved by utilizing the post hoc Tukey test. The test did not show a significant difference among the three subgroup of GIS experience in system quality. Therefore, the K-W test results utilized which report a significant difference between the subjects who are experts (more than 6 years of experience) with a reported mean rank of

48 and those who are professionals (between 2-6 years of experience) with a reported mean rank of 34. However, those who are beginners (less than 2 years of experience) subgroup with a reported mean rank of 43 did not differ from experts or professionals. This might be interpreted that the GIS experts have more experience with GIS software features and capabilities and feel more confident in the software quality for crisis applications than the GIS professionals.

<u>Research Hypothesis 3:</u> There are significant differences in GIS effectiveness in crisis management among GIS users based on duration of training as perceived in system quality, information quality, user satisfaction, system use, individual decision making, task complexity and feedback, and organizational impact.

Test Findings: According to the test result presented, there is no significant difference among GIS users training subgroups (less than 6 months, between 6 to 12 months, and more than 12 months) in the effectiveness of GIS in crisis management as perceived in system quality, information quality, user satisfaction, system use, individual decision-making, task complexity/ feedback, and organizational impact. The analyzed data did not provide sufficient evidence to reject the null hypothesis. Table 8 provides a summary of the five research hypotheses testing findings.

Table 8. Summary of the Research Hypotheses Testing Findings

Ind.Variable / Ded.Variable	(H1) Position [Directors& project managers, technical, or users]	(H2) Work Experience [<2, between 2 to 6, or >6 Years]	(H3) Duration of Training [< 6, between 6 to12, or >12 Months]
System Quality	Not Significant	Significant	Not Significant
Information quality	Not Significant	Not Significant	Not Significant
User satisfaction	Not Significant	Not Significant	Not Significant
System use	Significant	Not Significant	Not Significant
Decision making	Not Significant	Not Significant	Not Significant
Task complexity/ Feedback	Significant	Not Significant	Not Significant
Organization-al Impact	Significant	Not Significant	Not Significant

6. Operation and Policy Recommendations

Based on this research, it is possible to make a number of recommendations that should result in more effective utilization of GIS. The following recommendations come directly from the research:

1. GIS managers should regularly measure the GIS effectiveness for each project or crisis events and establish a log. At the same time, they may consider other technical, individual and organizational factors to be measured in the model according to the crisis context. Therefore, the log data will show how the crisis events or projects are being managed. Additionally, the above measurements will improve the effectiveness of GIS, which will affect on the organizational performance.
2. The decision-making model of GIS effectiveness was used for the crisis applications domain. This is to avoid any potential for distorted or biased data by using GIS for different domains of applications. The model can be used for other GIS applications such as transportation, urban planning, telecommunication and so forth.
3. Future development and refinement of measurements are needed. It is important to highlight the need to review the appropriateness of the GIS measurements according to GIS future capabilities, crisis context, and organization needs.

7. Recommendations for Further Study

1. This study captured information from the GIS population in crisis management that includes all levels or classes of employees. This study surveyed GIS directors and GIS project managers, GIS technical staff, and GIS users. While managers surely represent a major group within organizations using GIS in this study, users are equally important. GIS end-users represented the smallest sample size in this study. Therefore, future research that targets this class of employees and compares them to managers is clearly needed. Such research is important in furthering our understanding of the myriad issues that have been addressed herein in terms of user satisfaction.
2. For the four crisis management phases of preparedness, response, recovery, mitigation, some respondents replied to all different four-crisis phases. Therefore, the independence of the subjects was lacking. Therefore, the repeated multi variant analysis of variance (MANOVA) procedure could be used, provided there was sufficient sample size. However, there were not enough observations or respondents for the four-crisis phases simultaneously to use MANOVA to find any significant differences in GIS effectiveness in crisis management among the four phases of crisis management.
3. User satisfactions factors were assessed the lowest among the other six factors of GIS. More specific research is recommended to investigate the GIS users satisfaction in the field of crisis management. Additionally, a comparative study may needed to find how GIS users differ from other information systems applications users that may add value to the GIS research literature.
4. Another way of doing this study would be to allow the GIS users to prioritize the GIS effectiveness model and have experts assess the model factors through a survey. Then a comparative study will be needed to compare the model evaluation from the users' point of view and the experts' point of view.

5. In order to achieve effective GIS technology and to capture the potential benefits from employing the new technology, the factors associated with it should be studied at various future stages of growth and development of GIS. Other system technical features and the consideration of particular organizational functions in relation to GIS implementation could also be incorporated in future research.
6. Team Expert Choice that employs the Analytical Hierarchy Process does not perform pairwise comparison between sub-factors that are not related to the same factor by assuming that those sub-factors are independent from each other. However, there are some relation between the GIS sub-factors that are not relate to the same factor such easy to use sub-factor and training provided to user sub-factor. Therefore, another decision making technique may be considered for developing GIS effectiveness model.
7. This study did not address specific GIS software features as a sub-factor of the system quality factor. Team Expert Choice (educational version) allows no more than nine nodes (factors) in each level, which then forces the nodes to the next lower level. Thus, future studies may include these GIS features such as polygon overlay, networking, and so forth under the sub-factor of GIS data manipulation.

8. Concluding Remarks

GIS is a spatial information system that needs to be managed properly in order to be used effectively. The GIS development and evaluation research that has been published to date in the literature by information systems researchers has concentrated primarily on public sector organizations and on measuring technical system features rather than individual behavior and organizational factors that affecting success [20]. Moreover, there is not a systematic study of GIS evaluation across multiple organizations that has been published [20].

This study presents the first research that focused on technical, as well as individual, and organizational factors that affects GIS success. More importantly, this study may be considered the first empirical study that introduces a systematic model to measure GIS effectives, and that surveyed across multiple public and private organizations.

GIS is rapidly becoming an integral part of the crisis management. GIS managers work under a great deal of pressure in case of a crisis. Their line of work demands high levels of precision delivered in the least amount of time. If GIS variables are managed effectively, the potential exists to reduce cost, shorten time of planning, improve crisis preparedness, response, recovery, and mitigation operations, and reduce organization performance deficiencies.

Moreover, the crisis management field may be now mature enough to use knowledge gained from GIS effectiveness measurements and leverage this knowledge in improving the quality of existing GIS technology and periodically examine its use in the field.

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